Diffusion-Prepared Fast Imaging with Steady-State Free Precession (DP-FISP): A Rapid Diffusion MRI Technique at 7T

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Introduction

Diffusion MRI has proven to be an extremely useful imaging technique with demonstrated clinical applications including stroke, neurodegenerative diseases, cancer, kidney disease, and liver disease [1-3]. The large majority of diffusion MRI studies have utilized Echo-Planar Imaging (EPI) acquisition techniques which provide a much shorter acquisition time in comparison to spin echo acquisitions. However, EPI techniques are susceptible to off-resonance distortion and eddy current artifacts which are extremely problematic on high field (≥7T) human and small animal MRI scanners. In this study, we have developed a novel Diffusion Prepared - Fast Imaging with Steady-State Free Precession (DP-FISP) MRI acquisition technique to provide DWI data in ~500ms and robust Diffusion Tensor Imaging (DTI) data at 7T in approximately 1 minute with vastly decreased artifacts in comparison to EPI acquisitions.

Materials and Method

Pulse Sequence: All acquisitions were implemented on a Bruker Biospec 7T MRI scanner equipped with a 400 mT/m gradient insert. The DP-FISP pulse sequence (**Fig. 1**) combines a slice-selective diffusion preparation (90_x-180_y-90_{-x}) with a single-shot, centrically-encoded FISP acquisition [4] to provide diffusion-weighted images in less than 500ms. Bipolar diffusion gradients were used to minimize motion artifacts (**Fig. 1**). A FISP imaging readout was used to avoid banding artifacts, and centric encoding was utilized to preserve the diffusion weighting in the FISP images. The slice thickness of the diffusion preparation was larger than for the FISP imaging slice to ensure uniform diffusion preparation across the entire FISP imaging slice.

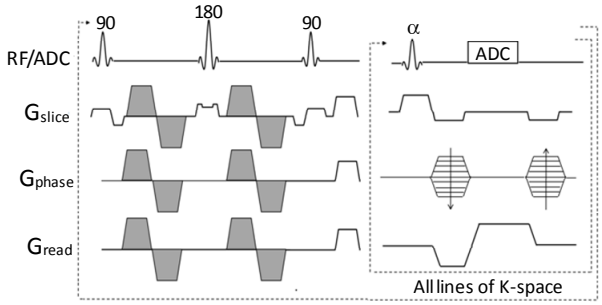

Figure1. Diagram for DP-FISP sequence

Phantom Validation: DTI images of a cylindrical water phantom were obtained to compare the accuracy of the DP-FISP technique (b=0.4 and 514 s/mm^2, 7 directions, TR/TE = 2.6msec / 1.3msec, α=60°, resolution = 0.3×0.3×2mm, , scan time = 1 min/average, NA=15) with a conventional spin echo DTI acquisition (b=0.4 and 534 s/mm^2, 7 directions, DTI-SE, TR/TE= 2500msec / 20 msec, resolution = 0.3 x 0.3 x 2mm, scan time = 38 min/average, NA=4). A delay of 8 seconds was applied after each DP-FISP acquisition to limit the effects of T1 relaxation. Apparent Diffusion Coefficient (ADC), diffusion eigenvalues (λ_1, λ_2, λ_3), and Fractional Anisotropy (FA) maps were calculated from the respective diffusion weighted images according to established methods.

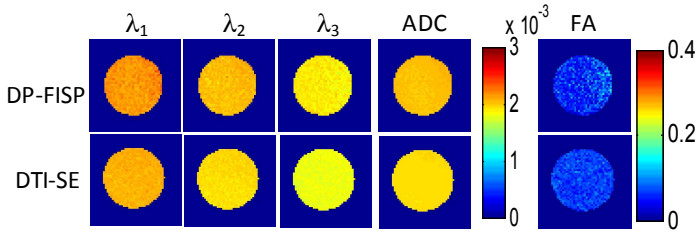

Figure 2. Comparative DTI maps of a water phantom for DP-FISP and DTI-spin echo acquisitions. Note the similar quantitative results for both acquisitions.

***In vivo* Evaluation:** The DP-FISP acquisition was also used to acquire coronal DTI images of the kidneys of a 2-month old PCK rat model of polycystic kidney disease with known renal cysts (TR/TE = 3.3msec / 1.65msec, b = 0.4 and 330 s/mm^2, resolution = 0.5 x 0.5 x 2mm, scan time = ~60 sec / average, NA=1). ADC maps were obtained as for phantom studies.

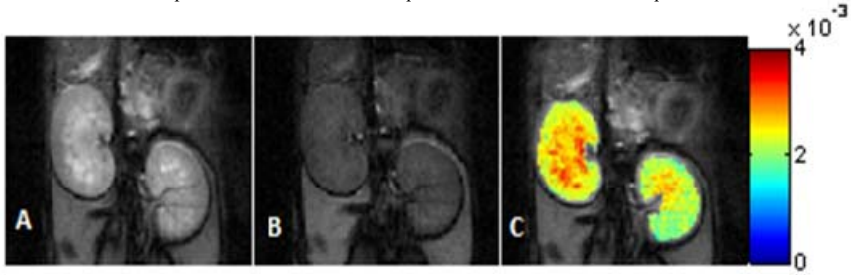

Figure3. In vivo study on rat kidney with DP-FISP methods. (A) diffusion-weighted images (b = 0.4 s/mm^2); (B) diffusion-weighted images (b = 330 s/mm^2); (C) ADC maps.

Results and Discussion

The phantom DTI results (**Fig. 2**) obtained from the DP-FISP acquisition (mean ADC=2.02x10^{-3} mm^2/sec, mean FA=0.07) were comparable to the gold standard DTI-SE results (mean 1.95×10^{-3} mm^2/sec, mean FA = 0.07). In addition, the SNR/time of the DP-FISP DTI acquisition was five times higher than for DTI-SE. The DP-FISP acquisition also exhibited minimal artifacts in comparison to EPI acquisitions (images not shown). Representative *in vivo* diffusion weighted images and ADC maps of polycystic rat kidneys are shown in **Figure 3**. Corticomedullary cysts are evident in both the diffusion weighted images (hyperintense regions) as well as the ADC maps (red regions) demonstrating the sensitivity of the DP-FISP technique to known pathology. Noncystic regions of the rat kidneys (cortex) exhibited ADC values of 2.0-2.5 mm2/sec which were comparable to published results for human kidneys [3].

Conclusions

These initial results demonstrate that the DP-FISP acquisition provides rapid and quantitatively accurate diffusion MRI data on a 7T small animal MRI scanner. Phantom and in vivo results demonstrate that high quality diffusion weighted images can be obtained in ~500ms, and that DTI image sets (7 directions) can be obtained in ~1 minute. Overall, the DP-FISP acquisition provides diffusion MRI data in the same acquisition time as EPI techniques but with greatly decreased image artifacts, especially for in vivo applications.

References

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